Engineering

We are supporting Laboratory programs, industrial competitiveness, and national needs by turning scientific ideas into working technology.

Engineering focuses its efforts on developing the staff, tools, and facilities needed to support current and future LLNL programs and technologies critical to the nation. These efforts are guided by a dual-benefit research and development strategy that encourages nuclear deterrence to enhance national security and partnerships with U.S. industry to increase economic competitiveness.

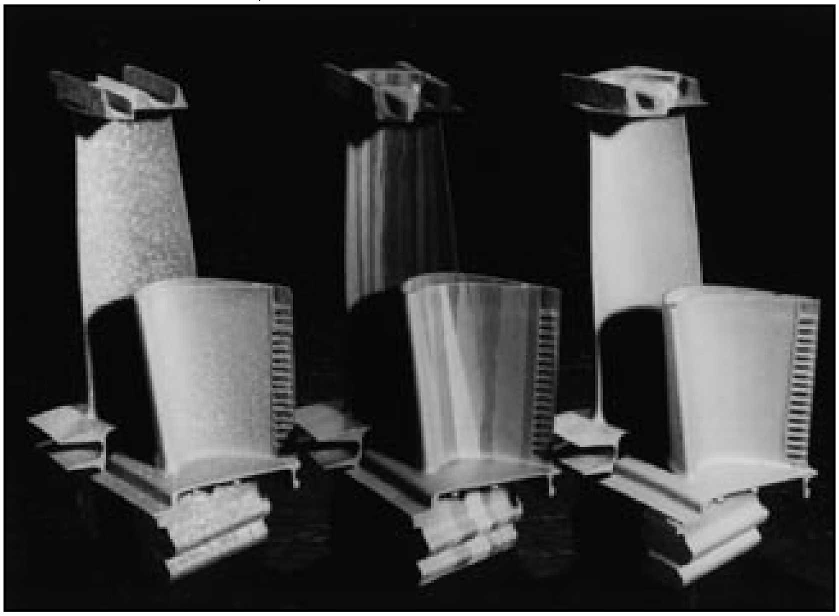
The engineering personnel who design, fabricate, test, and install prototype systems to support LLNL programs are skilled in many disciplines. These broad skills allow them to work on projects throughout the Laboratory. The cutting-edge technologies they develop in doing these projects often suggest new programmatic directions. At the same time, new programmatic goals may stimulate ideas for engineering research and development.

Engineering's efforts are organized into seven integrated activities:

- Computational electronics and electromagnetics.
- Computational mechanics.
- Diagnostics and microelectronics.
- Fabrication technology.
- Materials science and engineering.
- Nondestructive evaluation.
- Power-conversion technologies.

As a natural outgrowth of our work with unique materials, microelectronics, and ultrahigh-precision machining, we have developed a spectrum of special facilities. They include facilities for materials fabrication, nondestructive evaluation, materials development, measurement and endurance testing, and microelectronics fabrication.

Turbine blades cast using (from left) the equiax (randomly grown, equisized crystals), polycrystal (unidirectional crystals), and single-crystal (one unidirectional crystal) processes.



Computational Electronics and Electromagnetics

Computational Electronics and Electromagnetics develops and implements theory and techniques into codes for analyzing electronic and electromagnetic phenomena. We also focus on the design of electrical devices. In 1994, we assessed the performance of high-speed interconnects, developed techniques for millimeter-wave sintering of ceramic materials, and used electromagnetic tomography to characterize reservoirs for oil-well logging. Under the auspices of the Department of State, we also collaborated in microwave electronics with institutes and companies in the former Soviet Union.

We have joined in cooperative research and development agreements (CRADAs) with industry to develop components for communication electronics, opto-electronics and photonics, and microwave heating systems for magnetic fusion energy. Internationally, we participate in Europe's 1-MW Free-Electron-Maser experiment. We also analyze and design components for high-current particle accelerators for fusion energy and radiography, analyze defects in laser mirrors for the proposed National Ignition Facility, and perform electromagnetic interference and radar cross-section computations for electrically large structures such as aircraft.

Parallel Mesh Generation

We are moving our three-dimensional simulation codes to massively parallel processors. The task of generating the meshes needed for simulation belongs to the Parallel Mesh Generation project, which is developing a code to construct large (up to 1 billion elements) polyhedral meshes. When completed, it will support three-dimensional physics codes for electromagnetics, structural mechanics, thermal analysis, and hydrodynamics and significantly enhance LLNL's capabilities in physical simulation.

Computational Mechanics

Computational Mechanics develops general-purpose software for heat transfer and for solid, structural, and fluid mechanics. This software has achieved international fame as part of our collaborators program. The codes have also formed the basis for several technology transfer initiatives and were extended to industrial uses in casting, metalforming, and automobile crash dynamics. They continue to be the cornerstone of support for LLNL programs.

In FY 1994, we worked on ParaDyn, our next-generation solid/structural mechanics code, which will be used on massively parallel computers and extend performance from gigaflop to teraflop power. We also moved DYNA3D, our best-known code, to the Meiko CS-2 256 parallel processor, emphasizing research into parallel algorithms for automobile crash dynamics; did a comprehensive seismic analysis of the Dumbarton Bridge for Caltrans; perfected the simulation of superplastic forming of metals in NIKE3D for two CRADAs; and demonstrated the PING code for large-scale acoustics simulation on the Cray YMP, later moving it to the Cray T3d for an even larger simulation.

Casting Process Modeling

We are working with Howmet Corporation and UES, Incorporated, to develop a single computer code to predict the strength, porosity, deformation, and shape of cast metal parts (such as aerospace alloys) prior to casting. Our NIKE and TOPAZ codes are currently used with the UES-developed ProCAST code for fluid–thermal–mechanical analyses of the process for casting turbine blades for jet engines. Howmet, which produces such blades, is supplying experimental casting data for software validation. When completed, this effort should improve casting quality, reduce manufacturing time and design costs, and improve Howmet's competitiveness in the international aerospace industry.

Diagnostics and Microelectronics

Diagnostics and Microelectronics concentrates on microfabrication-based technology (largely using semiconductor materials) such as gallium-arsenide and silicon microelectronics. This includes miniature electrophoresis channels for DNA analysis, polymerase chain-reaction chambers for DNA replication, and miniaturized flow cytometers. It also includes diagnostics for environmental and health-care uses and microtools for endovascular techniques.

Highlights for 1994

- Developed parallel mesh generation to construct polyhedral meshes on massively parallel computers.
- Combined our NIKE and TOPAZ codes with an industrial modeling code to analyze casting of jet-engine turbine blades.
- Developed in conjunction with Biology and Biotechnology a flow cytometer to sort biological cells via light scattering, using a semiconductor diode laser as a light source and a silicon photodiode/preamp module as a detector.
- Developed smart microtools for minimally invasive intravascular surgery.
- Designed a diamond grinding wheel for glass optics and ceramic parts.
- Devised an accelerated lifetime methodology to predict and enhance fiber-polymer composite strength and durability.
- Developed a cheaper, safer radioactive-waste-drum inspection system to eliminate radiation risk.
- Developed nondestructive procedures to evaluate materials for automobile engine parts.
- Produced a compact power source for solid-state laser-diode arrays.

At LLNL's Microtechnology Center, we design and build microanalytical instruments, micromechanical sensors and actuators, and semiconductor diode lasers and optical amplifiers. We also build electronic and photonic devices for high-speed transient data acquisition in biology, biotechnology, health care, and nuclear nonproliferation.

Flow Cytometer

We replaced the ion-laser light sources in flow cytometers (which use light scattering to classify and sort biological cells) with semiconductor diode lasers and substituted silicon photodiode/preamp modules for their photomultiplier-tube light detectors. We also invented (patent pending) a method for collecting right-angle-scattered light by trapping it in the liquid flow stream, which acts as an optical waveguide, and allowing it to propagate through a fiber optic to the silicon-based light detector. This method increases the signal by an order of magnitude, produces less background noise, and is two to three times more accurate.

With 1 to 2 volts of input power, this 400-μm-long intravascular microtool from the Microtechnology Center will curl up and stretch out in liquid. The Center's ongoing research into microscale actuators includes their use in areas such as optics, biomedical instruments, and micropart packaging.

Intravascular Microtools

We are working with the UC San Francisco Medical School to develop smart microtools to improve minimally invasive intravascular techniques. Our efforts focus on fabricating and demonstrating microtools that incorporate robotic steering, microactuation mechanisms, and sensors. We are also attempting to improve the imaging ability of commercially available intravascular imaging systems with enhanced computer-vision algorithms. This work is expected to produce smart intravascular catheter systems for remote therapeutic intervention.

Fabrication Technology

Fabrication Technology focuses on building a manufacturing technology base adequate to conduct future Laboratory business. We are studying and characterizing fundamental fabrication processes, building general-purpose and fabrication models, and transferring technology to LLNL programs and industry. We also have relationships with industry and academia to advance our collective understanding of fabrication processes. Our niche, however, will continue to be precision engineering.

We sponsored three projects in FY 1994. The first was in molecular modeling technology, which helps us understand fabrication processes on the scale of atoms and molecules. As precision processes continue to be refined, the molecular level will define our ultimate limits of precision. The second project characterized the limit to which a commercial double-sided lap process can generate flat optical components, which prepared us for purchasing flat components for the proposed National Ignition Facility. In the third, we used a diamond–metal composite to develop a single-layer, precision, diamond grinding wheel.

Diamond Grinding Wheel

A programmatic need for a precision grinding tool to manufacture glass optics and ceramic parts led to a diamond grinding wheel. This wheel has a single layer of fine diamond powder chemically attached to a substrate of high precision and complex shape. We have already produced several wheels using commercially available diamond powder in the 6- to 12-mm size range. Analyses show a single layer of diamonds uniformly dispersed over the resulting surfaces. This success has led to four more grinding wheels and several prototype cutoff saw blades for test and evaluation.

Materials Science and Engineering

Materials Science and Engineering studies relationships between the processing, structure, and properties of materials of interest to LLNL and industry to enhance our understanding of the physical and mechanical behavior of structural materials. We use LLNL finite-element codes in an iterative fashion to further our capabilities in material processing, particularly composites (such as metal-matrix and polymer composites) and superplastics (crystalline solids capable of extremely high elongations).

In FY 1994 we achieved diffusion bonding of Aluminum 7475 concurrently with superplastic forming in a low-pressure argon atmosphere. We also characterized the metal/ceramic interface of Al/Al_2O_3 by measuring the interface strength and toughness of specimens prepared by ultrahigh-vacuum diffusion bonding. We studied the lamination process of two metal composites, one made of ultrahigh carbon steel and brass and another made of Al 5182 and Al 6090 (with 25% SiC particulate for strength), which were prepared by hot-pressing alternate layers in an argon gas atmosphere. Then tensile properties and fracture toughness were measured and correlated to processing conditions, such as surface treatment, relative volume fractions of component materials, and heat treatments. We also designed and built a biaxial gas pressure apparatus, which we are using to examine the effect of hydrostatic pressure on cavitation and thinning characteristics of superplastic aluminum alloy 7475.

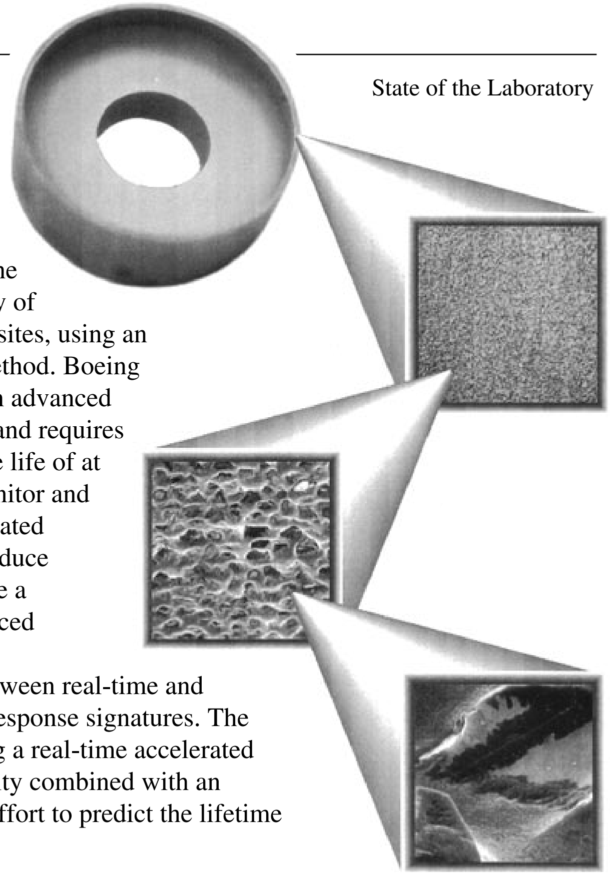
Continuous Fiber–Polymer Composites

We joined Boeing Commercial Airplane Group in a five-year, $18.5-million CRADA to predict and enhance the strength and durability of fiber–polymer composites, using an accelerated testing method. Boeing uses these materials in advanced aviation applications and requires them to have a service life of at least 13 years. To monitor and verify that our accelerated method does not introduce artificial aging, we use a combination of advanced techniques to develop comparative maps between real-time and accelerated material response signatures. The focus is on developing a real-time accelerated materials testing facility combined with an integrated modeling effort to predict the lifetime material response.

Nondestructive Evaluation

Nondestructive Evaluation provides cutting-edge technologies for the advancement of inspection tools. We inspect finished parts and complex objects to detect flaws and fabrication defects and to determine their physical and chemical characteristics. We also design sensors and monitors for process control and in-service damage.

In FY 1994, we converted three-dimensional tomographic data for CAD/CAM systems and produced dimensional measurements with a semiautomated reverse engineering process that provides rapid turnaround for prototyping and manufacturing parts. We are also developing infrared computed tomography to find hidden corrosion. Using a technique that detects small temperature differences from heat-flow anomalies, we can predict airframe, bridge-deck, and pipeline damage before it occurs. We have already shown the feasibility of using a dual-band infrared system for concrete bridge-deck inspections. Furthermore, we have been working with ultrasonic evaluation, which uses sound waves to detect flaws or anomalies and to identify material parameters. We have looked at replacing traditional ultrasonic nondestructive evaluation with a laser-generated



Single-layer diamond grinding wheel. The photographs show the uniform distribution of diamond powder (low magnification, top), the swarf relief that surrounds it (medium magnification, middle), and the good metal-matrix-to-diamond bonding (high magnification, bottom).

ultrasonic method, which has potential to measure material parameters and shapes during in-process manufacturing and allows remote, noncontacting evaluation to be performed in a furnace or kiln.

Waste-Drum Inspection

We are working with Bio-Imaging Research, as well as with LLNL's Nuclear Chemistry and A-Division and UC San Francisco, on a drum inspection system called waste-inspection tomography (WIT). This system will allow inspectors to look into but not open the hundreds of thousands of drums of radioactive waste produced by the government, industry, hospitals, and universities. Currently, these drums must be inspected before they can be transported from temporary sites to permanent storage, but opening them costs $10,000 to $100,000 per drum and entails the risk of radiation exposure to inspectors and the environment. WIT, in contrast, could reduce inspection costs to $250 to $400 per drum and eliminate radiation releases.

WIT will allow inspectors to measure internal drum radiation to identify and find radioisotopes, determine the presence and volume of waste items, and locate nonradioactive materials such as gloves and beakers. It will also be faster than noninvasive radiographic inspection techniques and provide sharper, three-dimensional images of the drums' contents. Further, it should satisfy regulatory requirements for treating, shipping, and permanently storing radioactive waste.

Evaluation of Lightweight Materials

General Motors is evaluating new lightweight materials, particularly metal-matrix composites, as alternatives to cast-metal parts for automobile engines. We have recommended nondestructive evaluation methods for production-line testing in the manufacturing environment. To screen every part that passes through the production line, these methods must be fast, rugged, inexpensive, and reliable. We will also design a production-line ultrasonic scanner to detect unacceptable porosity in the earliest possible manufacturing stage.

Power-Conversion Technologies

The microwave and pulsed power group changed its name to Power-Conversion Technologies to reflect its expanded emphasis and scope to address more power-conversion issues. At the same time, we began developing new technologies to prepare our engineering directorate

A waste-inspection tomography unit allows inspectors to measure the radiation inside drums without opening them. The unit provides sharper images than other radiographic techniques and is safer and less expensive.

to meet future program needs and to help solve national problems related to the efficient use of electrical power. We focus on the use of advanced power electronics, energy storage, and dense packaging technologies, emphasizing ways to improve compactness, efficiency, cost, and reliability for future power-conversion technologies.

We support several technologies to align with LLNL programmatic interests and potential industrial collaborations. In the ground-penetrating imaging radar project, we are developing impulse radar technologies to inspect roadbeds and bridge decks for construction flaws and age- or wear-related degradation. In the ferroelectric emitter project, we are evaluating ferroelectric materials as new electron beam sources for Site 300's FXR accelerator. For the high-gradient insulator project, we are examining the application of "micro-stack" insulator technologies for very compact, high-voltage generator designs. In the compact power-source project, we are developing a compact, solid-state power source for driving solid-state laser diodes.

Compact Power Supplies

High-power laser-diode arrays are finding application in areas from advanced manufacturing to medicine. Unfortunately, power for such arrays has been supplied by one large power source external to and isolated from the array, which is too cumbersome to be practical. To correct this, we are developing a standard power source that is simple to operate, efficient, compact, cost-effective, and integral to the diode array. By integrating laser diodes and local decision-making capability with a solid-state power control called MOSFET (metal-oxide semiconductor field-effect transistor) and an insulated-gate bipolar transistor, we produced a "smart" power source that can respond quickly to changes in temperature or fault conditions, which will preserve performance, protect the diodes, and improve diode products.

Personnel Development

Our directorate joined Stanford University, UC Davis, and CSU Chico in 1971 to set up a two-way instructional television program for LLNL and Sandia engineers. It is transmitted on 29 color channels to 500 LLNL locations and affiliated with the National Technological University. Through the program, UC Davis has awarded 100 graduate (M.S. and Ph.D.) degrees; Stanford and CSU Chico have also issued many graduate degrees.

In addition, we sponsor more than 60 on-site courses in current and new technologies. The latest group of classes helps managers, investigators, and administrators better understand program development. During FY 1994, we had a total of more than 12,000 participants.

We also completed a pilot mentoring program with 16 mentoring pairs and expanded the program in September 1994. Our goals are to fully use all engineers, increase awareness of diverse workforce needs, enhance new employees' knowledge and abilities, and provide career tools. Most program graduates learned more about career steps and department resources; others improved their listening skills and ability to use constructive criticism.

For further information contact
Dave Pehrson (510) 422-8351.